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XXI. Further Observations on the Spectra of some of the Stars and Nebulae, with an Attempt to determine therefrom whether these Bodies are moving towards or from the Earth, also Observations on the Spectra of the Sun and of Comet II., 1868.
By WILLIAM HUGGINS, F.R.S.

Received April 23*,—Read May 14, 1868.

§ I. *Introduction.*

IN a paper “On the Spectra of some of the Fixed Stars”† by myself and Dr. W. A. MILLER, Treas. R.S., we gave an account of the method by which we had succeeded during the years 1862 and 1863 in making trustworthy simultaneous comparisons of the bright lines of terrestrial substances with the dark lines in the spectra of some of the fixed stars. We were at the time fully aware that these direct comparisons were not only of value for the more immediate purpose for which they had been undertaken, namely, to obtain information of the chemical constitution of the investing atmospheres of the stars, but that they might also possibly serve to tell us something of the motions of the stars relatively to our system. If the stars were moving towards or from the earth, their motion, compounded with the earth’s motion, would alter to an observer on the earth the refrangibility of the light emitted by them, and consequently the lines of terrestrial substances would no longer coincide in position in the spectrum with the dark lines produced by the absorption of the vapours of the same substances existing in the stars.

The apparatus employed by us was furnished with two prisms of dense flint glass, each with a refracting angle of 60° , and permitted the comparisons to be made with so much accuracy that the displacement of a line, or of a group of lines, to an amount smaller even than the interval which separates the components of FRAUNHOFER’s D would have been easily detected. We were, therefore, in possession of the information that none of the stars the lines in the spectra of which we had compared with sufficient care, were moving in the direction of the visual ray with a velocity so great, relatively to that of light, as to shift a line through an interval corresponding to a difference of wavelength equal to that which separates the components of D. To produce an alteration of refrangibility of this amount, a velocity of about 196 miles per second would be required. The following stars, with some others, were observed with the requisite accuracy:—Aldebaran, α Orionis, β Pegasi, Sirius, α Lyrae, Capella, Arcturus, Pollux, Castor.

[* This date of reception applies to the part of the paper containing the observations on the stars and nebulae. The part containing the observations on the sun was received April 30; that containing the observations on Comet II., 1868, was received July 2, and is printed in continuation of the paper read May 14.—G. G. S.]

† Philosophical Transactions, 1864, p. 413.

It appeared premature at the time to refer to these negative results, as it did not seem to be probable that the stars were moving with velocities sufficiently great to cause a change of refrangibility which could be detected with our instrument. The insufficiency of our apparatus for this very delicate investigation does not, however, diminish the trustworthiness of the results we obtained respecting the chemical constitution of the stars, as the evidence for the existence or otherwise of a terrestrial substance was made to rest upon the coincidence, or want of coincidence in general character as well as position of *several lines*, and not upon that of a single line.

According to the undulatory theory, light is propagated with equal velocity in all directions, whether the luminous body be at rest or in motion. The change of refrangibility is therefore to be looked for from the diminished or increased distance the light would have to traverse if the luminous object and the observer had a rapid motion towards or from each other. The great relative velocity of light to the known planetary velocities, and to the probable motions of the few stars of which the parallax is known, showed that any alterations of position which might be expected from this cause in the lines of the stellar spectra would not exceed a fraction of the interval between the double line D, for that part of the spectrum.

I have devoted much time to the construction and trial of various forms of apparatus with which I hoped to accomplish the detection of so small an amount of change of refrangibility. The difficulties of this investigation I have found to be very great, and it is only after some years that I have succeeded in obtaining a few results which I hope will be acceptable to the Royal Society.

The subject of the influence of the motions of the heavenly bodies on the index of refraction of light had already, at the time of the publication of our paper in 1864, occupied the attention of Mr. J. C. MAXWELL, F.R.S., who had made some experiments in an analogous direction. In the spring of last year, at my request, Mr. MAXWELL sent to me a statement of his views and of the experiments which he had made. I have his permission to enrich this communication with the clear statement of the subject which is contained in his letter, dated June 10, 1867.

In 1841, DOPPLER showed that since the impression which is received by the eye or the ear does not depend upon the intrinsic strength and period of the waves of light and of sound, but is determined by the interval of time in which they fall upon the organ of the observer, it follows that the colour and intensity of an impression of light, and the pitch and strength of a sound will be altered by a motion of the source of the light or of the sound, or by a motion of the observer, towards or from each other*.

DOPPLER endeavoured by this consideration to account for the remarkable differences of colour which some of the binary stars present, and for some other phenomena of the heavenly bodies. That DOPPLER was not correct in making this application of his theory is obvious from the consideration that even if a star could be conceived to be moving with

* "Ueber das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels," Böhm. Gesell. Abh. ii. 1841-42, s. 465.

a velocity sufficient to alter its colour sensibly to the eye, still no change of colour would be perceived, for the reason that beyond the visible spectrum, at both extremities, there exists a store of invisible waves which would be at the same time exalted or degraded into visibility, to take the place of the waves which had been raised or lowered in refrangibility by the star's motion. No change of colour, therefore, could take place until the whole of those invisible waves of force had been expended, which would only be the case when the relative motion of the source of light and the observer was several times greater than that of light.

In 1845, BALLOT published a series of acoustic experiments which support DOPPLER's theory in the case of sound. In the same paper BALLOT advances several objections to DOPPLER's application of his theory to the colours of the stars*.

This paper was followed by several papers by DOPPLER in reply to the objections which were brought against his conclusions†.

In 1847 two memoirs were published by SESTINI on the colours of the stars in connexion with DOPPLER's theory‡.

More recently, in 1866, KLINKERFUES§ published a memoir on the influence of the motion of a source of light upon the refrangibility of its rays, and described therein a series of observations from which he deduces certain amounts of motion, in the case of some of the objects observed by him.

The method employed by KLINKERFUES has been critically discussed by Dr. SOHNCKE||.

It may be sufficient to state that as KLINKERFUES employs an achromatic prism, it does not seem possible, by his method of observing, to obtain any information of the motion of the stars; for in such a prism the difference of period of the luminous waves would be as far as possible, annulled. It is, however, conceivable that his observations of the light when travelling from E. to W., and from W. to E., might show a difference in the two cases, arising from the earth's motion through the ether.

Father SECCHI has quite recently called attention to this subject¶. In his paper he states that he has not been able to detect any change of refrangibility in the case of certain stars, of an amount equal to the difference between the components of the double line D. These results are in accordance with those obtained by myself and Dr. MILLER in 1863, so far as they refer to the stars which had been examined by us.

Father SECCHI's method of using an unrefracted image as a fiducial mark with diverging rays passing through the prisms might, it is conceivable, be open to objection.

* "Akustische Versuche auf der Niederländischen Eisenbahn nebst gelegentlichen Bemerkungen zur Theorie des Hrn. Prof. DOPPLER," Pogg. Ann. B. lxvi, s. 321.

† See Pogg. Ann. B. lxxxii. s. 270, and Pogg. Ann. B. lxxxvi. s. 371.

‡ Memoria sopra i colori delle stelle del catalogo de Baily osservati dal P. BAND SESTINI. Roma, 1847.

§ "Fernere Mittheilungen über den Einfluss der Bewegung der Lichtquelle auf die Brechbarkeit eines Strahls, von W. KLINKERFUES," Nachr. K. G. der W. zu Göttingen, No. 4, s. 33.

|| "Ueber den Einfluss der Bewegung der Lichtquelle auf die Brechung, kritische Bemerkungen zu der Entdeckung des Hrn. Prof. KLINKERFUES. Von Hrn. Dr. SOHNCKE, Astron." Nachr. No. 1646.

¶ Comptes Rendus, 2 Mars 1868, p. 398.

He appears to consider that, to produce a certain alteration of refrangibility, half the velocity would be required in the case of the approach of a star to that which would be necessary if the star were receding. This is not the case, for equal velocities of separation or approach give equal changes of wave-length. It is true that a difference of an octave is produced by a relative velocity of separation equal to that of light, and by a velocity of approach equal to half that of light; but the difference in length of a wave and its octave below (which is twice as long) is in the same proportion greater than the difference between it and the octave above (which is half as long).

The experiments of M. FIZEAU in connexion with this subject are referred to by Mr. MAXWELL in the following statement of his views and experiments, which was received by me on June 12, 1867.

On the Influence of the Motions of the Heavenly Bodies on the Index of Refraction of Light.

Let a source of light be such that it produces n disturbances or vibrations per second, and let it be at such a distance from the earth that the light requires a time T to reach the earth. Let the distance of the source of light from the earth be altered, either by the motion of the source of light, or by that of the earth, so that the light which emanates from the source t seconds afterwards reaches the earth in a time T' .

During the t seconds nt vibrations of the source of light took place, and these reached the earth between the time T and the time $t+T'$, that is, during $t+T'-T$ seconds. The number of vibrations which reached the earth per second was therefore no longer n , but $n \frac{t}{t+T'-T}$.

If v is the velocity of separation of the source of light from the earth, and V the velocity of light between the bodies relative to the earth, then $vt = V(T-T')$, and the number of vibrations per second at the earth will be $n \frac{V}{V+v}$.

If V_0 is the velocity of propagation of light in the luminiferous medium, and if v_0 is the velocity of the earth,

$$V = V_0 - v_0,$$

and the wave-length will be increased by a fraction of itself equal to

$$\frac{v}{V_0 - v_0}.$$

Since v_0 only introduces a correction which is small compared even with the alteration of wave-length, it cannot be determined by spectroscopic observations with our present instruments, and it need not be considered in the discussion of our observations.

If, therefore, the light of the star is due to the combustion of sodium, or any other element which gives rise to vibrations of definite period, or if the light of the star is absorbed by sodium vapour, so as to be deficient in vibrations of a definite period, then the light, when it reaches the earth, will have an excess or defect of rays whose period of vibration is to that of the sodium period as $V+v$ is to V .

As an example, let us suppose the star to be fixed and the earth to be moving directly away from the star with the velocity due to its motion round the sun. The coefficient of aberration indicates that the velocity of light is about 10,000 times that of the earth in its orbit, and it appears from the observations of ÅNGSTRÖM and DITSCHEINER that the wave-length of the less refrangible of the lines forming D exceeds that of the other by about one-thousandth part of itself. Hence, if the lines corresponding to D in the light of the star are due to sodium in the star, these lines in the starlight will be less refrangible than the corresponding lines in a terrestrial sodium-flame by about a tenth part of the difference between D_1 and D_2 .

When the earth is moving towards the star, the lines will be more refrangible than the corresponding terrestrial lines by about the same quantity.

The effect of the proper motion of stars would of course have to be compounded with the effect of the earth's own motion, in order to determine the velocity of approach or separation.

To observe these differences of the light from stars, a *spectroscope* is necessary, that is, an instrument for separating the rays of different periods; and it is immaterial in what direction the refraction of the light through the prisms takes place, because the *period* of the light is the thing to be observed by comparison with that of a terrestrial flame.

If, instead of a spectroscope, an achromatic prism were used, which produces an equal deviation on rays of different periods, no difference between the light of different stars could be detected, as the only difference which could exist is that of their period.

If the motion of a luminiferous medium in the place where the experiment is made is different from that of the earth, a difference in the deviation might be expected according to the *direction* of the ray within the prisms, and this difference would be nearly the same whatever the source of the light.

There are therefore two different and independent subjects of experiment. The one is the alteration in the period of vibration of light due to the relative motion of the stars and the earth. The fact of such an alteration is independent of the form under which we accept the theory of undulations, and the possibility of establishing its existence depends on the discovery of lines in the stellar spectra, indicating by their arrangement that their origin is due to the existence of substances in the star having the same properties as substances found on the earth. Any method of observing small differences in the period of vibration of rays, if sufficiently exact, will enable us to verify the theory, and to determine the actual rate of approach or separation between the earth and any star.

The other subject of experiment is the relation between the index of refraction of a ray and the direction in which it traverses the prism. The essentials of this experiment are entirely terrestrial, and independent of the source of light, and depend only on the relative motion of the prism and the luminiferous medium, and on the direction in which the ray passes through the prism.

The theory of this experiment, however, depends on the form in which we accept the theory of undulations. In every form of the theory, the index of refraction depends on

the retardation which a ray experiences on account of having to traverse a dense medium instead of a vacuum. Let us calculate this retardation.

Let there be a transparent medium whose thickness is a , and let it be supposed fixed. Let the luminiferous ether be supposed to move with velocity v in air, and with velocity v' within the medium. Let light be propagated through the ether with velocity V in air and with velocity V' within the medium. Then the absolute velocity of the light will be $v+V$ in air and $v'+V'$ within the medium, and the retardation, or difference of *time* in traversing a thickness a of the medium and an equal thickness of air, will be

$$a\left(\frac{1}{v'+V'} - \frac{1}{v+V}\right);$$

and the retardation in *distance* reckoned as at the velocity, V will be

$$a\left\{\frac{V}{V'} - 1 - \frac{v'}{V}\left(\frac{V^2}{V'^2} - \frac{v}{v'}\right) + \frac{v'^2}{V^2}\left(\frac{V^3}{V'^3} - \frac{v^2}{v'^2}\right) - \&c.\right\}.$$

Now, according to every form of the theory, $\frac{V}{V'} = \mu$, the index of refraction, and according to FRESNEL's form of the theory, in which the density of the medium varies as μ^2 , the equation of continuity requires that $\frac{v}{v'} = \mu^2$. In this case the second term disappears and the retardation is $a(\mu-1) + \text{terms in } \frac{v'^2}{V^2}$, which may be neglected, as V is more than 10000 times v .

Hence, on FRESNEL's theory, the retardation due to the prism is not sensibly affected by the motion of the earth. The same would be true on the hypothesis that the luminiferous ether near the earth's surface moves along with the earth, whatever the form of the theory of the medium.

Since the deviation of light by the prism depends entirely on the retardation of the rays within the glass, no effect of the earth's motion on the refrangibility of light is to be expected. Professor STOKES (Phil. Mag. 1846, p. 63) has also given a direct proof of this statement, and the experiment of ARAGO confirms it to a certain degree of exactness.

In order to test the equality of the index of refraction for light moving in opposite directions through a prism, I employed in 1864 the following arrangement.

I made use of a spectroscope constructed by Mr. BECKER, and provided with a tube at right angles to the axis of the observing-telescope, carrying a transparent plate of parallel glass placed between the object-glass and its focus, so as to reflect the light which enters the tube along the axis of the telescope towards the object-glass. In this tube is placed a screen with a vertical slit, in the middle of which is a vertical spider-line so arranged that its virtual image formed by the first surface of the glass plate coincides with the crossing of the spider-lines of the telescope at the principal focus of the object-glass. This coincidence is tested by observing the cross lines through the other telescope, with the two telescopes facing each other. The eyepiece of the second telescope is then removed, and a plane mirror is placed at the focus of the object-glass, perpendicular to the axis, and the telescopes are so adjusted that light entering by the side tube is

reflected down the axis of the first telescope, traverses the prisms in succession, enters the second telescope, is reflected by the mirror at its focus, and emerges from the telescope parallel to its direction at incidence; it then traverses the prisms in the reverse order, and is brought to a focus at the cross lines of the first telescope.

If the deviation of the rays in passing through the prisms from east to west differs from that produced during their passage from west to east, the image of the vertical spider-line formed by the rays which have traversed the prisms twice will not coincide with the intersection of the spider-lines as before.

I have found, however, that when the instrument is properly adjusted, the coincidence is so perfect with respect to rays of all refrangibilities, that the image of the vertical spider-line is seen with perfect distinctness, though the rays which form it have passed twice through three prisms of 60° .

If we observe the coincidence of this image with the intersection of the spider-lines at the focus when the rays pass through the prisms first in the direction of the earth's motion and return in the opposite direction, we may then reverse the whole instrument, so that the rays pursue an opposite path with respect to the earth's motion. I have tried this experiment at various times of the year since the year 1864, and have never detected the slightest effect due to the earth's motion. If the image of the spider-line is hid by the intersection of the cross lines in one position, it remains hid in precisely the same way in the other position, though a deviation corresponding to one-twentieth of the distance of the components of the line D could be easily detected.

On the other hand, M. FIZEAU* has observed a difference in the rotation of the plane of polarization according as the ray travels in the direction of the earth's motion or in the contrary direction, and M. ÅNGSTRÖM has observed a similar difference in phenomena of diffraction. I am not aware that either of these very difficult observations has been confirmed by repetition.

In another experiment of M. FIZEAU, which seems entitled to greater confidence, he has observed that the propagation of light in a stream of water takes place with greater velocity in the direction in which the water moves than in the opposite direction, but that the acceleration is less than that which would be due to the actual velocity of the water, and that the phenomenon does not occur when air is substituted for water. This experiment seems rather to verify FRESNEL's theory of the ether; but the whole question of the state of luminiferous medium near the earth, and of its connexion with gross matter, is very far as yet from being settled by experiment.

June 10, 1867.

JAMES CLERK MAXWELL.

§ II. *Description of Apparatus.*

All the experiments were made with my refractor by ALVAN CLARK, of 8 inches aperture and 10 feet focal length, which is mounted equatorially, and carried very smoothly

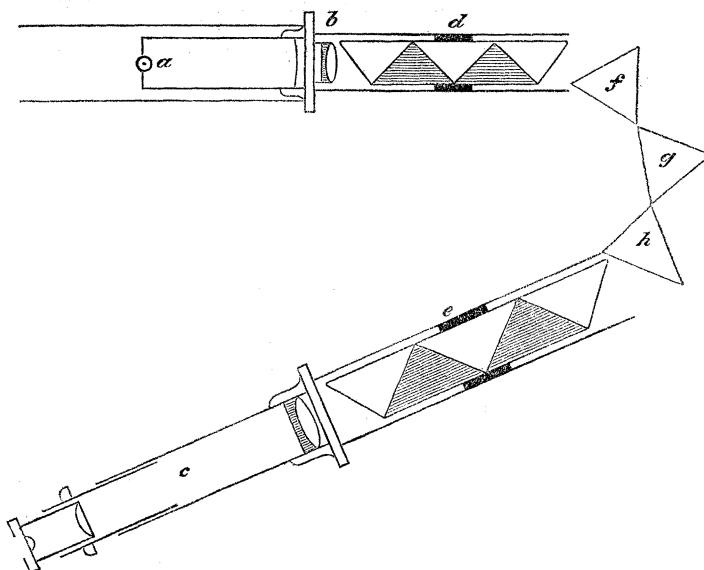
* Ann. de Chimie et de Physique, Feb. 1860.

by a clock-motion. As even on nights of unusual steadiness the lines in the spectra of the stars are necessarily, for several reasons, more difficult of minute discrimination of position than are those of the solar spectrum, it is important that the apparatus employed should give an ample amount of dispersion relatively to the degree of minuteness of observation which it is proposed to attempt.

In 1866 I constructed a spectroscope for the special objects of research described in this paper, which was furnished with three prisms of 60° of very dense flint glass. The solar lines were seen with great distinctness. I found, however, that, in order to obtain a separation of the lines sufficient for my purpose, an eyepiece magnifying ten or twelve diameters was necessary. Under these circumstances the stellar lines were not seen in the continued steady manner which is necessary for the trustworthy determination of the minute differences of position which were to be observed. After devoting to these observations the most favourable nights which occurred during a period of some months, I found that if success was to be obtained, it would probably be with an apparatus in which a larger number of prisms and a smaller magnifying power were employed.

The inconvenience arising from the pencils, after passing through the prisms, crossing those from the collimator when more than three or four prisms are employed, and also, in part, the circumstance that I had in my possession two very fine direct-vision prisms on AMICI's principle, which had been made for me by HOFMANN of Paris, induced me to attempt to combine in one instrument several simple prisms with one or two compound prisms which give direct vision. An instrument constructed in this way, as will be seen from the following description, possesses several not unimportant advantages*.

a is an adjustable slit; *b* an achromatic collimating lens of 4·5 inches focal length;



c represents the small telescope with which the spectrum is viewed. The train of prisms

* [An apparatus in many respects superior to the one here described has been constructed since.—October 1868.]

consists of two compound prisms, *d* and *e*, and three simple prisms, *f*, *g*, *h*. Each of the compound prisms contains five prisms, cemented together with Canada balsam. The shaded portions of the diagram represent the position of the two prisms of very dense flint glass in each compound prism. The compound prism marked *e* is much larger than the other, and is permanently connected with the telescope *c*, with which it moves. These compound prisms, which were made specially to my order by HOFMANN, are of great perfection, and produced severally a dispersion fully equal to two prisms of ordinary dense flint glass. The prisms *f* and *g* were cut for me from a very fine piece of dense glass of Guinand by Messrs. SIMMS, and have each a refracting angle of 60° . The prism *h* was made by Mr. BROWNING from the dense flint glass manufactured by Messrs. CHANCE, this prism has a refracting angle of 45° . The great excellence of all these prisms is shown by the very great sharpness of definition of the bright lines of the metals when the induction-spark is taken before the slit, even when considerable magnifying power is employed on the small telescope with which the spectrum is viewed. The instrument is provided with a second collimator, of which the object-glass has a focal length of 18 inches.

The compound prism *e* is so fixed that it can be removed at pleasure, when the total dispersive power of the instrument is reduced from about six and a half prisms of 60° , to about four and a half prisms of 60° . The facility of being able to reduce the power of the instrument has been found to be of much service for the observation of faint objects, and also on nights when the state of the atmosphere was not very favourable.

The telescope with which the spectrum is viewed is carried by a micrometer-screw, which, however, has not been employed for taking measures of the spectra, but only for the purpose of setting the telescope to the part of the spectrum which it is intended to observe. This precaution is absolutely necessary when nebulae are observed which emit light of two or three refrangibilities only.

For the purpose of the simultaneous comparisons of the light of the heavenly bodies with the lines of the terrestrial elements, the slit was provided, in the usual way, with a small prism placed over one half of it, which received the light reflected upon it from a small mirror placed opposite the electrodes. The plan of observation formerly employed, and which is described in the paper "On the Spectra of some of the Fixed Stars," was adopted to ensure perfect accuracy of relative position in the instrument between the star-spectrum and the spectrum to be compared with it, since it is possible by tilting the mirror to alter within narrow limits the position of the spectrum of the terrestrial substance relatively to that of the star. Before commencing an observation, a small alcohol-lamp, in the wick of which bicarbonate of soda was placed, was fixed before the object-glass of the telescope, and then the mirror and the electrodes were so adjusted that the components of the double line D were exactly coincident in both spectra.

This plan was soon found to be very inconvenient, and even in some degree untrustworthy for the more delicate comparisons which were now attempted. An unobserved accidental displacement of the spark, or of the mirror, might cause the two spectra to differ in position by an amount equal to the whole extent of want of coincidence which

it was proposed to seek for in this investigation. The observations of many nights have been rejected, from the uncertainty as to the possible existence of an accidental displacement.

Another inconvenience, so great as even to seem to diminish the hope of ultimate success, was found to arise from the difficulty of bringing the lower margin of the star-spectrum into actual contact with the upper margin of the spectrum of the light reflected into the instrument. The lines in the spectra of the stars are not, on ordinary nights, so steady and distinct as are those of the solar spectrum. Under these difficult circumstances it is very desirable, as an assistance to the eye in its judgment of the absolute identity or otherwise of the position of lines, that the bright lines of comparison should not merely meet the dark lines in the star-spectrum, but that they should overlap them to a small extent. When the two spectra are so arranged as to be in contact, the eye is found to be influenced to some extent by the apparent straightness or otherwise of the compound line formed by the coincident, or nearly coincident lines in the two spectra. Owing to the unavoidable shortness of the collimator the lines in a broad spectrum are slightly curved. From this cause the determination of the identity of lines in spectra which are in contact merely is rendered more difficult, and it may be less trustworthy.

The difficulties of observation which have been referred to were in the first instance sought to be overcome by placing the spark before the object-glass of the telescope. In some respects this method appears to be unexceptionable, but there are disadvantages connected with it. The bright lines, under these circumstances, extend across the star-spectrum, and make the simultaneous observation of dark lines, which are coincident, or nearly so with them, very difficult. When the spark is taken between open electrodes, the consequent disturbance of the air in front of the object-glass is unfavourable to good definition. An important disadvantage arises from the great diminution in the brightness of the spark from the distance (10 feet) at which it is placed from the slit; since in consequence of its nearness to the object-glass, the divergence of the light from it is diminished in a small degree only by that lens. It is obvious that, by means of a lens of short focal length placed between the spark and the object-glass, the light from the spark might be rendered parallel or even convergent; but the adjustments of such a lens, so that the pencils transmitted by it should coincide accurately in direction with the optical axis of the telescope, would be very troublesome. When two Leyden jars, connected as one jar, were interposed, and the spark was taken in air between platinum points, there was visible in the spectroscope only the brightest of the lines of the air-spectrum, namely, the double line belonging to nitrogen, which corresponds to the principal line in the spectra of the gaseous nebulae. When a vacuum-tube containing hydrogen at a low tension was placed before the object-glass, the line corresponding to F was seen with sufficient distinctness, but the line in the red was visible with difficulty. Some observations, however, have been made with the spark arranged before the object-glass.

The following arrangement for admitting the light from the spark appeared to me to be free from the objections which have been referred to, and to be in all respects adapted

to meet the requirements of the case. In place of the small prism, two pieces of silvered glass were securely fixed before the slit at an angle of 45° . In a direction at right angles to that of the slit, an opening of about $\frac{1}{10}$ inch was left between the pieces of glass for the passage of the pencils from the object-glass. By means of this arrangement the spectrum of a star is seen accompanied by two spectra of comparison, one appearing above, and the other below it. As the reflecting surfaces are about 0.5 inch from the slit, and the rays from the spark are divergent, the light reflected from the pieces of glass will have encroached upon the pencils from the object-glass by the time they reach the slit, and the upper and lower spectra of comparison will appear to overlap to a small extent the spectrum formed by the light from the object-glass. This condition of things is of great assistance to the eye in forming a judgment as to the absolute coincidence or otherwise of lines. For the purpose of avoiding some inconveniences which would arise from glass of the ordinary thickness, pieces of the thin glass used for the covers of microscopic objects were carefully selected, and these were silvered by floating them upon the surface of a silvering solution. In order to ensure that the induction-spark should always preserve the same position relatively to the mirror, a piece of sheet gutta percha was fixed above the silvered glass; in the plate of gutta percha, at the proper place, a small hole was made of about $\frac{1}{20}$ inch in diameter. The ebonite clamp containing the electrodes is so fixed as to permit the point of separation of these to be adjusted exactly over the small hole in the gutta percha. The adjustment of the parts of the apparatus was made by closing the end of the adapting-tube, by which the apparatus is attached to the telescope, with a diaphragm with a small central hole, before which a spirit-lamp was placed. When the lines from the induction-spark, in the two spectra of comparison, were seen to overlap exactly, for a short distance, the lines of sodium from the light of the lamp, the adjustment was considered perfect. The accuracy of adjustment has been confirmed by the exact coincidence of the three lines of magnesium with the component lines of *b* in the spectrum of the moon.

In some cases the spectra produced by the spark are inconveniently bright for comparison with those of the stars and nebulae. If the spark is reduced in power below a certain point, many of the lines are not then well developed; the plan, therefore, was adopted of diminishing the brightness of the spectrum, by a wedge of neutral-tint glass which can be moved at pleasure between the plate of gutta percha and the silvered mirror.

Two eyepieces were employed with the apparatus, the one magnifying four diameters, and the other six diameters.

The induction-coil was the same which I employed in my former observations. It was excited by a form of bichromate-of-potash battery, which I have found so exceedingly convenient for the occasional work of celestial observations that I will describe it here.

The battery, which was made for me by Mr. LADD, consists of two large cells of ebonite, each of which contains two plates of graphite, 6 inches by $7\frac{1}{2}$ inches, connected

together with copper bands. These plates are fixed into varnished plates of wood, which form covers to the cells. In each wooden cover is a slit of the length of the width of the carbon plates, by which an amalgamated zinc plate can be inserted between the plates of graphite. An important part of the arrangement is a third large cell of ebonite, which is filled with water acidulated with a few drops of sulphuric acid, and contains at the bottom some mercury. As soon as a plate is removed from the battery after use, it is rubbed clean under running water, and then immersed in the spare cell until it is again required. By this arrangement the plates are always clean and perfectly amalgamated. The solution employed to charge the battery is a saturated solution of bichromate of potash, to which about $\frac{1}{10}$ part of sulphuric acid has been added. The battery is sufficiently powerful and always ready for instant use. For the convenience of varying the power of the battery, three sets of zinc plates are kept in the spare cell; the plates are 2 inches, 4 inches, and 6 inches in width.

§ III. *Observations of Nebulæ.*

For the greater convenience of reference and of comparison, the spectrum of 37 H. IV. Draconis from my paper "On the Spectra of some of the Nebulæ"*, has been added to fig. 2, Plate XXXIII. The spectrum of this nebula may be taken as characteristic, in its general features, of the spectra of all the nebulae which do not give a continuous spectrum. At present I have determined satisfactorily the general characters of the spectra of about seventy nebulae. This number forms but a part of the much larger list of nebulae which I have examined, but in the case of many of these objects their light was found to be too feeble for a satisfactory analysis. Of these seventy nebulae about one-third give a spectrum of bright lines. The proportion, which is indicated by this examination, of the nebulae which give a spectrum of bright lines to those of which the spectrum is continuous (namely, as one to two), is probably higher than would result from a wider observation of the objects contained in such catalogues as those of Sir JOHN HERSCHEL and Dr. D'ARREST, since many of the objects which I examined were specially selected, on account of the probability (which was suggested by their form or colour) that they were gaseous in constitution.

All the differences which I have hitherto observed between the spectra of the gaseous nebulae may be regarded as modifications only of the typical form of spectrum which is represented in the diagram, since they consist of differences of relative intensity, of the deficiency of one or two lines, or of the presence of one or two additional lines. It is worthy of remark that, so far as the nebulae have been examined, the brightest of the three lines, which agrees in position in the spectrum with the brightest of the lines of the spectrum of nitrogen, is present in *all* the nebulae which give a spectrum indicative of gaseity. It is a suggestive fact that should not be overlooked, that in no nebula which has a spectrum of bright lines, has any additional line been observed on the less refrangible and brighter side of the line common to all the gaseous nebulae.

* *Philosophical Transactions*, 1864, p. 438.

The faint continuous spectrum, which in some cases is also seen, has been traced in certain nebulae, by its breadth, to a distinct brighter portion of the nebula which it is convenient still to distinguish by the term "nucleus," though at present we know nothing of the true relation of the bright points of the nebulae to the more diffused surrounding portions.

It must not be forgotten that when gases are rendered luminous there may usually be detected a faintly luminous continuous spectrum. In the case of several of the nebulae, such as the annular nebula of Lyra and the Dumb-bell nebula, no existence of even a faint continuous spectrum has been yet certainly detected.

The determination of the position in the spectrum of the three bright lines was obtained by simultaneous comparison with the lines of hydrogen, nitrogen, and barium. The instrument which I employed had two prisms, each with a refracting angle of 60°, and the positions of the lines were trustworthy within the limits of about the breadth of the double line D.

The objects which I proposed to myself, in attempting a reexamination of some of the nebulae with the large instrument described in this paper, were to determine, first, whether any of the nebulae were possessed of a motion which could be detected by a change of refrangibility; secondly, whether the coincidence which had been observed of the first and the third line with a line of hydrogen and a line of nitrogen would be found to hold good when subjected to the test of a spreading out of the spectrum three or four times greater than that under which the former observations were made. It would not, it seemed, be difficult, in the case of the detection of a want of coincidence, to separate the effects of the two distinct sources referred to, from both of which equally a minute difference of refrangibility between the nebular lines and those of terrestrial substances might arise. The probability is very great indeed that in all the nebulae which give the kind of spectrum of which I am speaking, the two lines referred to are to be attributed to the same two substances, and that therefore, in all these nebulae, they were originally of the same degree of refrangibility. On the other hand, it is not to be supposed that nebulae situated in different positions in the heavens would have a similar motion relatively to the earth. An examination of several nebulae would therefore show to which of these causes any observed want of coincidence was to be attributed.

The Great Nebula in Orion.—In my description of this nebula* I stated that the light from all the parts of this strangely diversified object, which were bright enough to be observed with my instrument, was resolved into three bright lines similar to those represented in the diagram.

On the present occasion I applied myself in the first place to as careful a comparison as possible of the brightest line with the corresponding line of the spectrum of nitrogen.

My first observations were made with the light from the induction-spark taken in pure nitrogen sealed in a tube at a tension a little less than that of the atmosphere, which

* Proceedings of the Royal Society, vol. xiv. p. 39.

was reflected into the instrument, as in my former series of observations, by means of a mirror and a small prism. The precaution was taken to verify the accuracy of the position of the spectrum of comparison relatively to that of the nebula, by placing a small lamp before the object-glass in the way already described.

The coincidence of the line in the nebula with the brightest of the lines of nitrogen, though now subjected to a much more severe trial, appeared as perfect as it did in my former observations. I expected that I might discover a duplicity in the line in the nebula corresponding to the two component lines of the line of nitrogen, but I was not able, after long and careful scrutiny, to see the line double. The line in the nebula was narrower than the double line of nitrogen; this latter may have appeared broader in consequence of irradiation, as it was much brighter than the line in the nebula.

The following observations are suggestive in connexion with the point under consideration. Electrodes of platinum were placed before the object-glass in the direction of a diameter, so that the spark was as nearly as possible before the centre of the lens. The spark was taken in air. I expected to find the spectrum faint, for the reasons which have been stated in a previous paragraph, but I was surprised to find that only one line was visible in the large spectroscope when adapted to the eye-end of the telescope. This line was the one which agrees in position with the line in the nebula, so that under these circumstances the spectrum of nitrogen appeared precisely similar to the spectra of those nebulae, of which the light is apparently monochromatic. This resemblance was made more complete by the faintness of the line; from which cause it appeared much narrower, and the separate existence of its two components could no longer be detected. When this line was observed simultaneously with that in the nebula, it was found to appear but a very little broader than that line. When the battery circuit was completed, the line from the spark coincided so accurately in position with the nebular line, that the effect to the eye was as if a sudden increase of brightness in the line of the nebula had taken place. In order to make this observation, and to compare the relative appearance of the lines, the telescope was moved so that the light from the nebula occupied the lower half only of the slit. The line of the spark was now seen to be a very little broader than the line of the nebula, and appeared as a continuation of it in an unbroken straight line. These observations were repeated many times on several nights.

An apparent want of coincidence, which would be represented by 0.02 division of the head of the micrometer-screw, would be about the smallest difference that could be observed under the circumstances under which these observations were made. At the part of the spectrum where this line of nitrogen occurs, the angular interval measured by 0.02 division of the micrometer corresponds to a difference of wave-length of 0.0460 millionth of a millimetre.

At the time the comparisons were made the earth was receding from the part of the heavens in which the nebula is situated by about half its orbital velocity. If the velocity of light be taken at 185,000 miles per second, and the wave-length of the nitrogen

line at 500.80 millionths of a millimetre, the effect of half the orbital motion would be to degrade the refrangibility of the line by 0.023, an alteration of wave-length which would correspond to about 0.01 of the large micrometer-head, an interval too small to be detected.

We learn from these observations, that if the line be emitted by nitrogen, the nebula is not receding from us with a velocity greater than ten miles per second; for this motion, added to that of the earth's orbital velocity, would have caused a want of coincidence that could be observed. Further, that if the nebula be approaching our system, its velocity may be as much as twenty miles or twenty-five miles per second; for part of its motion of approach would be masked by the effect of the motion of the earth in the contrary direction.

The double line in the nitrogen-spectrum does not consist of sharply defined lines, but each component is nebulous, and remains of a greater width than the image of the slit*. The breadth of these lines appears to be connected with the conditions of tension and of temperature of the gas. PLÜCKER† states that when an induction-spark of great heating-power is employed, the lines expand so as to unite and form an undivided band. Even when the duplicity exists, the eye ceases to have the power to distinguish the component lines, if the intensity of the light be greatly diminished.

Though I have been unable to detect duplicity in the corresponding line in the nebula, it might possibly be found to be double if seen under more favourable conditions; I incline to the belief that it is not double‡.

In my Tables of the lines of the air § I estimated the brightness of each of the components of the double line in the spectrum of nitrogen at 10, and the components of the double line next in brightness in the orange at 7 and 5, and those of a third double line on the less refrangible side of D at 6 and 4. It was with reference to these two double lines next in apparent brilliancy that I wrote||, in speaking of the line in the nebula, "If, however, this line were due to nitrogen, we ought to see other lines as well; for there are specially two strong double lines in the spectrum of nitrogen, one at least of which, if they existed in the light of the nebulae, would be easily visible."

As the disappearance of the whole spectrum of nitrogen, with the exception of the one double line, was unexpected, though, indeed, in accordance with my previous estimations, I examined the spectrum of nitrogen with a spectroscope furnished with one prism with a refracting angle of 60°, in which the whole of the spectrum from C to G is included in the field of view. I then moved between the eye and the little telescope of the spectroscope a wedge of neutral-tint glass corrected for refraction by an inverted similar

* SECCHI states that with his direct spectroscope this line in the annular nebula in Lyra appears double. As the image of the nebula is viewed directly, after elongation by the cylindrical lens, and without a slit, it is probable that the two lines may correspond to the two sides of the elongated annulus of the nebula.

† Philosophical Transactions, 1863, p. 13.

‡ "On the Spectra of the Chemical Elements," Philosophical Transactions, 1864, p. 141.

§ Ibid.

|| Ibid. p. 443.

wedge of crown glass, and which I had found to be sensibly equal in absorbing power on the different parts of the visible spectrum. As the darker part of the wedge was brought before the eye, the two groups in the orange were quite extinguished, while the lines in the green still remained of considerable brightness. The line which under these circumstances remained longest visible next to the brightest line, was one more refrangible at 2669 of the scale of my map. This observation was made with a narrow slit. When the induction-spark was looked at from a distance of some feet with a direct-vision prism held close to the eye, I was surprised to observe that the double line in the orange appeared to me to be the brightest in the spectrum, and when the neutral-tint wedge was interposed, this line in the orange remained alone visible, all the other lines being extinguished.

When, however, in place of the simple prism a small direct-vision spectroscope provided with a slit was employed, I found it to be possible, by receding from the spark, to find a position in which the double line in the green, with which the line in the nebula coincides, was alone visible, and the spectrum of the spark in nitrogen resembled that of a monochromatic nebula.

It is obvious that if the spectrum of hydrogen were reduced in intensity, the line in the blue, which corresponds to that in the nebula, would remain visible after the line in the red and the lines more refrangible than F had become too feeble to affect the eye.

It therefore becomes a question of much interest whether the one, two, three, or four lines seen in the spectra of these nebulae represent the whole of the light emitted by these bodies, or whether these lines are the strongest lines only of their spectra which, by reason of their greater intensity, have succeeded in reaching the earth. Since these nebulae are bodies which have a sensible diameter, and in all probability present a continuous luminous surface, or nearly so, we cannot suppose that any lines have been extinguished by the effect of the distance of these objects from us.

If we had evidence that the other lines which present themselves in the spectra of nitrogen and hydrogen were quenched on their way to us we should have to consider their disappearance as an indication of a power of extinction residing in cosmical space, similar to that which was suggested from theoretical considerations by CHÉSEAUX, and was afterwards supported on other grounds by OLBERS and the elder STRUVE. Further, as the lines which we see in the nebulae are precisely those which experiment shows would longest resist extinction, at least so far as respects their power of producing an impression on our visual organs, we might conclude that this absorptive property of space is not *elective* in its action on light, but is of the character of a *general* absorption acting equally, or nearly so, on light of every degree of refrangibility. Whatever may be the true state of the case, the result of this reexamination of the spectrum of this nebula appears to give increased probability to the suggestion that followed from my former observations, namely, that the substances hydrogen and nitrogen are the principal constituents of the nebulae of the class under consideration.

I now pass to observations of the third line of the nebular spectrum, the one which I

found to coincide with the line of hydrogen, which corresponds to FRAUNHOFER'S F. The substance in the nebulae which is indicated by this line appears to be subject to much greater variation in relative brilliancy, or to be more affected by the conditions under which it emits light; for while the brightest line is always present, the line of which I am speaking seems to be wholly wanting in some nebulae, and to be of different degrees of relative brightness in some other nebulae.

In the nebula of Orion this line is relatively stronger than in 37 H. IV. Draconis, and some other nebulae. I have suspected that the relative brightness of this line varies slightly in different parts of this nebula. It may be estimated perhaps in the nebula of Orion at about the brightness of the second line. The second line suffers in apparent brilliancy from its nearness to the brightest line, and may, without due regard to this circumstance, be estimated as brighter than the third line.

In order to compare the position of the line with that of the corresponding line in the spectrum of hydrogen, I employed a vacuum-tube containing hydrogen at a very small tension, which was placed before the object-glass of the telescope. Under these conditions the line appears narrow, when the slit is narrow, without any sensible nebulosity at the edges. The character of the line is altered, as has been shown by PLÜCKER, when hydrogen at the atmospheric pressure is employed; the line then expands into a nebulous band of considerable width, even with a very narrow slit. Such a condition of the line is obviously unsuitable for the delicate comparisons which it was proposed to attempt.

The narrow, sharply-defined line of hydrogen, when the vacuum-tube was before the slit, was observed to coincide perfectly in position with the third line of the nebula. This observation, which shows the coincidence of these lines with an accuracy three or four times as great as my former observations, increases in the same ratio the probability that the line in the nebula is really due to luminous hydrogen.

I suspect that although the third line in this nebula may impress the eye as strongly as the second line, yet it is not so narrow and well defined as that line. If this suspicion be correct, this condition of the line might indicate that the hydrogen exists at a rather greater tension than that in the so-called vacuum-tubes, but that it is not nearly so dense as would correspond to the atmospheric pressure at the surface of the earth. As, however, the character of the lines of hydrogen is also greatly modified by temperature it is not possible to reason with any certainty as to the state of things in this distant object, the light of which we have now under examination.

I am still unable to find any terrestrial line which corresponds to the middle line. I have made the additional observation that the line in the nebula is in a very slight degree less refrangible than the line of oxygen at 2060 of the scale of my map. It is in a rather larger degree less refrangible than the strong line of barium at 2075 of my scale.

Several other nebulae have been observed with the large spectroscope, I prefer, however, to re-examine these objects before I publish any observations of them.

§ IV. *Observations of Stars.*

The chief difficulties which I have had to encounter have arisen from the unsteadiness of our atmosphere. There is sufficient light from stars of the first and second magnitude for the large spectroscope described in this paper, and so far as the adjustments of the instrument are concerned, the lines in the spectra of the stars would be well defined. Unless, however, the air is very steady, the lines are seen too fitfully to permit of any certainty in the determination of coincidences of the degree of delicacy which is attempted in the present investigation. I have passed hours in the attempt to determine the position of a single line, and have then not considered that the numerous observations which I had obtained were possessed, even collectively, of sufficient weight to establish with any certainty the coincidence of the line with the one compared with it.

I prefer, therefore, to reject a large number of observations which appear unsatisfactory from this cause, and to give in this place a very few of the most trustworthy of the observations which I have made.

Sirius.—The brilliant light of this star and the great intensity of the four strong lines of its spectrum, make it especially suitable for such an examination. The low altitude of this star in our latitude limits the period in which it can be successfully observed to about one hour on each side of the meridian.

I have confined myself to comparisons of the strong line in the position of F, with the corresponding line of the spectrum of hydrogen. My first trials were made with hydrogen at the ordinary atmospheric pressure; the width of the band of hydrogen, under these circumstances, was greater than the line of Sirius. This line in Sirius, from some cause, is narrower relatively to the length of the spectrum, when considerable dispersion and a narrow slit are employed, than when the image of the star, rendered linear by a cylindrical lens, is observed with a single prism*.

When the large spectroscope was employed I estimated the breadth of the line to be about equal to that of the double line D. In KIRCHHOFF's map the line F of the solar spectrum is represented as a little more than one-fourth of the interval separating the lines D. When the spectroscope attached to the telescope was directed to the moon, the line F appeared even narrower than it is represented in KIRCHHOFF's map; I estimated it at about one-sixth of the apparent breadth of the corresponding line in the spectrum of Sirius. The character of the line agrees precisely with KIRCHHOFF's representation of the solar line F. It appears, as in the diagram, to be equally nebulous at both edges, and agrees in this respect precisely with the line of hydrogen under certain conditions of tension and temperature.

As it was obviously impossible to determine with the required accuracy the coincidence of the line of Sirius when the much broader band of hydrogen at the ordinary pressure was compared with it, I employed a vacuum-tube fixed before the object-glass. In all these observations the slit used was as narrow as possible. The air at the time of the present observations was more favourable than usual, and the line in Sirius was seen with

* See *Philosophical Transactions*, 1864, p. 42.

great distinctness. The line from the spark appeared, in comparison, very narrow, not more than about one-fifth of the width of the line of Sirius. When the battery circuit was completed, the line of hydrogen could be seen distinctly upon the dark line of Sirius, and extending to some distance on both sides of the spectrum of Sirius. The observation of the comparison of the lines was made many times, and I am certain that the narrow line of hydrogen, though it appeared projected upon the dark line in Sirius, did not coincide with the middle of the line, but crossed it at a distance from the middle, which may be represented by saying that the want of coincidence was *apparently* equal to about one-third or one-fourth of the interval separating the components of the double line D. I was unable to measure directly the distance between the centre of the line of hydrogen and that of the line in the spectrum of Sirius, but several very careful estimations by means of the micrometer give a value for that distance of 0.040 of the micrometer-head. This value is probably not in error by so much as its eighth part.

Comparisons on many other nights were also made, sometimes with the vacuum-tube before the object-glass, and sometimes with the vacuum-tube placed over the small hole in the gutta-percha plate. On all these occasions the numerous comparisons which were made, gave for the line in Sirius a very slightly lower refrangibility than that of the line of hydrogen, but on no one occasion was the air steady enough for a satisfactory determination of the amount of difference of refrangibility.

I have not been able to detect any probable source of error in this result, and it may therefore, I believe, be received as representing a relative motion of recession between Sirius and the earth.

The probability that the substance in Sirius by which this line is produced is really hydrogen, is strengthened almost to certainty by the consideration that there is a strong line in the red part of the spectrum which is also coincident with a strong line of hydrogen. There is a third line more refrangible than F, which appears to coincide with the line of hydrogen in that part of the spectrum.

As the line in Sirius is more expanded than that of the vacuum-tube, it seemed of importance to have proof from experiment that this line of hydrogen, when it becomes broad, expands equally in both directions. I made the comparison of the narrow line of the vacuum-tube with the more expanded band which appears when denser hydrogen is employed. For this purpose the intersection of the wires of the eyepiece was brought, as nearly as could be estimated, upon the middle of the expanded line which is produced by dense hydrogen. The vacuum-tube was then arranged before the slit, when the narrow line which it gives was observed to fall exactly upon the point of intersection of the wire. Under these terrestrial conditions the expansion of the line may be considered to take place to an equal amount in both directions. There is very great probability that a similar equal expansion takes place under the conditions which determine the absorption of light by this gas in the atmosphere of Sirius, for the reason that the nebulosity at the edges of the line in the spectrum of that star is sensibly equal on both sides.

I made some attempts to compare the strong line at C with the corresponding line of hydrogen; but when the large spectroscope was employed, though the lines could be seen with tolerable distinctness, they were not bright enough to admit of a trustworthy determination of their relative position. When one of the compound prisms was removed, the lines were much more easily seen, but under these circumstances the amount of dispersion was insufficient for my present purpose.

The lines of Sirius which, in conjunction with Dr. MILLER, I had compared with those of iron, magnesium, and sodium are not sufficiently well seen in our latitude for comparison, when a powerful train of prisms is employed, such as is necessary for this special inquiry.

From these observations it may, I think, be concluded that the substance in Sirius which produces the strong lines is really hydrogen, as was stated by Dr. MILLER and myself in our former paper. Further, that the aggregate result of the motions of the star and the earth in space, at the time when the observations were made, was to degrade the refrangibility of the line in Sirius by an amount corresponding to 0.040 of the micrometer-screw. Now the value of the wave-lengths of 0.01 division of the micrometer at the position of F is 0.02725 millionth of a millimetre*. The total degradation of refrangibility observed amounts to 0.109 millionth of a millimetre. If the velocity of light be taken at 185,000† miles per second, and the wave-length of F at 486.50 millionths of a millimetre (ÅNGSTRÖM's value is 486.52, DITSCHERER's 486.49), the observed alteration in period of the line in Sirius will indicate a motion of recession existing between the earth and the star of 41.4 miles per second.

Of this motion a part is due to the earth's motion in space. As the earth moves round the sun in the plane of the ecliptic, it is changing the direction of its motion at every instant. There are two positions, separated by 180° , where the effect of the earth's motion is a maximum, namely, when it is moving in the direction of the visual ray, either towards or from the star. At two other positions in its orbit, at 90° from the former positions, the earth's motion is at right angles to the direction of the light from the star, and therefore has no influence on its refrangibility.

The effect of the earth's motion will be greatest upon the light of a star situated in the plane of the ecliptic, and will decrease as the star's latitude increases, until with

* The value in wave-lengths of the divisions of the micrometer for different parts of the spectrum was determined by the aid of the tables of the wave-lengths corresponding to every tenth line of KIRCHHOFF's map by Dr. WOLCOTT GIBBS (SILLIMAN'S Journal, vol. xlvi. January 1867). A paper on the same subject by the Astronomer Royal, presented to the Royal Society, is not yet in print. [The Astronomer Royal's paper is contained in the Philosophical Transactions for 1868, Part I. p. 29. The wave-lengths computed by him differ slightly from those assigned to KIRCHHOFF's numbers by Dr. GIBBS at the part of the spectrum under consideration in the text. The difference is due in part to the employment, by the Astronomer Royal, of DITSCHERER's later measures. These give for F the higher value of 486.87.—October 1868.]

† The new determination of the value of the solar parallax by observations of Mars requires that the usually received velocity of light, 192,000 per second, should be reduced by about the one-twenty-seventh part. The velocity, when diminished in this ratio, agrees nearly with the result obtained by FOUCault from direct experiment.

respect to a star situated at the pole of the ecliptic, the earth's motion during the whole of its annual course will be perpendicular to the direction of the light coming to us from it, and will be therefore without influence on its period.

That part of the earth's resolved motion which is in the direction of the visual ray, and which has alone to be considered in this investigation, may be obtained from the following formula:

$$\text{Earth's motion towards star} = v \cdot \cos \lambda \cdot \sin (l - l'),$$

where v is earth's velocity, l the earth's longitude, l' the star's longitude, and λ the star's latitude.

At the time when the estimate of the amount of alteration of period of the line in Sirius was made, the earth was moving from the star with a velocity of about 12 miles per second.

There remains unaccounted for a motion of recession from the earth amounting to 29.4 miles per second, which we appear to be entitled to attribute to Sirius.

It may be not unnecessary to state that the solar motion in space, if accepted as a fact, will not materially affect this result, since, according to M. OTTO STRUVE's calculations, the advance of the sun in space takes place with a velocity but little greater than one-fourth of the earth's motion in its orbit. If the apex of the solar motion be situated in Hercules, nearly the whole of it will be from Sirius, and will therefore diminish the velocity to be ascribed to that star.

It is interesting, in connexion with the motion of Sirius deduced from these prismatic observations, to refer to the remarkable inequalities which occur in the rather large proper motion of that star. In 1851 M. PETERS* showed that the variable part of the proper motion of Sirius in right ascension might be represented by supposing that Sirius revolves in an elliptic orbit, round some centre of gravity without itself, in a period of 50.093 years. This hypothesis has acquired new interest, and seems indeed to have received confirmation from direct observation by ALVAN CLARK'S discovery of a small companion to Sirius.

Professor SAFFORD† and Dr. AUWERS‡ have investigated the periodical variations of the proper motion of Sirius in declination, and they have found that these variations, equally with those in right ascension, would be reconcileable with an elliptic orbital motion round a centre not in Sirius. The close coincidence of the observed positions of the new satellite with those required by theory, seem to show that it may be the hypothetical body suggested by PETERS, though we must then suppose it to have a much greater mass relatively to Sirius, than that which its light would indicate.

At the present time the proper motion of Sirius in declination is less than its average

* Astron. Nachrichten, No. 748.

† Proceedings of the American Academy, vol. vi.; also Astron. Notices, Ann. Arbor, No. 28; Monthly Notices, vol. xxii. p. 145.

‡ Astron. Nachrichten, No. 1506; Monthly Notices, vol. xxii. p. 148, and vol. xxv. p. 39.

amount by nearly the whole of that part of it which is variable. May not this smaller apparent motion be interpreted as showing that a part of the motion of the star is *now in the direction of the visual ray*? This circumstance is of much interest in connexion with the result arrived at in this paper.

Independently of the considerations connected with the variable part of the star's proper motion, it must not be forgotten that the whole of the motion which can be directly observed by us is only that portion of its real motion which is at right angles to the visual ray. Now it is precisely the other portion of it, which we could scarcely hope to learn from ordinary observations, which is revealed to us by prismatic investigations. By combining the results of both methods of research we may perhaps expect to obtain some knowledge of the real motions of the brighter stars and nebulae.

It seems therefore desirable to compare with the result obtained by the prism, the motion of Sirius which corresponds to its assumed constant proper motion. The values adopted by Mr. MAIN*, and inserted by the Astronomer Royal in the Greenwich 'Seven-year Catalogue,' are $-0''\cdot035$ in R.A., and $+1''\cdot24$ in N.P.D.

The parallax of Sirius from the observations of HENDERSON, corrected by BESSEL, $=0''\cdot150$. A recent investigation by Mr. C. ABBE† gives for the parallax the larger value of $0''\cdot27$. If the radius of the earth's orbit be taken at its new value of 91,600,000 miles, the assumed annual constant proper motion in N.P.D. of $1''\cdot24$ would indicate, with the parallax of HENDERSON, a velocity of Sirius of 24 miles nearly per second, with the larger parallax of Mr. ABBE, a velocity of 43.2 miles per second. It may be that in the case of Sirius we have two distinct motions, one peculiar to the star, and a second motion which it may share in common with a system of which it may form a part.

Observations and comparisons, similar to those on Sirius, have been made on α Canis Minoris, Castor, Betelgeux, Aldebaran, and some other stars. I reserve for the present the results which I have obtained, as I desire to submit these objects to a reexamination. It is seldom that the air is sufficiently favourable for the successful prosecution of this very delicate research.

§ V. *Observations of the Sun.*

Received April 30, 1868.

I have recently applied the large spectroscope described in this paper with some success to the examination of the spectrum of the umbra of a large sun-spot.

Before I describe the results of this examination, I will refer briefly to observations of the sun which I have made on many occasions, since 1864, with three distinct objects in view.

1. I have sought to discover if the spectrum of the light from near the sun's limb differs in any sensible degree from that of the light from the central parts of the disk.

* Memoirs of the Royal Astronomical Society, vol. xix.

† Monthly Notices of the Royal Astronomical Society, vol. xxviii. p. 2.

Since the diminished intensity of the marginal parts of the sun is probably due to the greater depth of solar atmosphere through which it had passed, it was conceivable that by its spectrum the light of these parts of the solar disk might exhibit some indications of the larger amount of absorbing medium which it had traversed.

Two different methods of observation were employed. The telescope, armed with one of the spectroscopes constructed for stellar observations, was directed to the sun. By the aid of the finder the telescope was moved so as to bring in succession upon the slit different parts of the solar disk. Though the detection of any difference depended upon the memory of the observer, still any considerable alteration would certainly have been noticed.

The other plan was to cause the sun's light, after reflection from a plane mirror attached to a heliostat moved by clockwork, to fall upon an achromatic object-glass of 6 feet focal length, by which an image of the sun was formed upon the slit of the large spectroscope which I employed for the examination of the spectra of the chemical elements.

By neither of these methods have I been able to detect any difference in the spectra of different parts of the sun's disk.

2. I have made numerous observations for the purpose of obtaining a view, if possible, of the red prominences which are seen during a solar eclipse. The invisibility of these objects at ordinary times is supposed to arise from the effect of the illumination of our atmosphere. If these bodies are gaseous, their spectra would consist of bright lines. With a powerful spectroscope the light from our atmosphere near the sun's limb would be greatly reduced in intensity by the dispersion of the prisms, while the bright lines of the prominences, if such were present, would remain but little diminished in brilliancy. These observations have been made with different spectroscopes, and also with other contrivances arranged on the same principle, but hitherto without success.

[The observations made in India of the solar eclipse of August 18 have shown that the spectra of the prominences are discontinuous. Lieut. HERSCHEL, R.E., who had charge of the instruments sent out by the Royal Society, determined approximately the position of three bright lines. One in the red about C, one apparently coincident with D, and one near F. On the day after the eclipse, M. JANSSEN, making use of a method similar to that described above, succeeded in observing the solar protuberances. On October 20, 1868, Mr. LOCKYER also succeeded in viewing the spectrum of a protuberance. Now that the positions of the lines are known, one of the "other contrivances" mentioned above will probably succeed. It consisted of screens formed of absorptive media, by which light of all refrangibilities other than those corresponding to the lines of the flames might be absorbed. By this method the flames could be examined and measured.—October 30, 1868.]

3. The third object which I had proposed to myself was to seek to gain from an examination of the spectra of the umbræ and penumbræ of solar spots some information as to the nature of these remarkable phenomena.

I had already made some experiments in this direction when in August 1866 I received

a note from M. FAYE, in which he suggests to me the prismatic examination of solar spots, since, according to his theory of the constitution of the sun, the spectrum of the umbra of a spot should be compound, consisting of a continuous spectrum with dark lines, and a second spectrum of bright lines. My first observations were made with a direct-vision spectroscope of HOFMANN, which was so arranged that the image of the sun was formed upon the slit, after the light had been enfeebled by reflection from a prismatic solar eyepiece.

When, by means of the finder, a spot was brought upon the slit, the feeble light from the umbra appeared as a narrow dark band upon the bright solar spectrum. The lines of FRAUNHOFER appeared stronger and thicker in the spectrum of the umbra.

In October 1866, Mr. LOCKYER, who had independently made similar observations, presented a paper to the Royal Society*, in which he states that he observed the lines of absorption of the solar spectrum to appear thicker where they crossed the spectrum of the spot. He also states that he saw no indication of the presence of bright lines.

It was not until April 15, 1868, that a favourable opportunity occurred to examine a large spot with the new spectroscope described in this paper.

The presence of some haze in the atmosphere permitted the spectroscope to be applied directly to the telescope, and the slit to be placed at the focus of the object-glass. The slit was rotated so that its length was in the direction of the length of the spot, and when the middle of the umbra fell upon the slit, its spectrum appeared as a feebly illuminated band upon the bright solar spectrum. The band appeared divided into two parts by the spectrum of the bright prominence, which extended nearly across the umbra.

The phenomenon of an increase of thickness of the lines of FRAUNHOFER, which I had previously observed, was very marked.

It was obvious that a part only of the light which appeared to form the spectrum of the umbra came from that particular region of the sun. The imperfect transparency of our atmosphere causes it to become strongly illuminated when the sun shines upon the earth; and the brilliant light which is seen to be radiated by it near the sun's limb, is also radiated by that portion of the atmosphere which is between the observer and the sun. It might be, therefore, that the whole of the light which appeared to come from the umbra was really due to the illuminated intervening atmosphere. That such was not the case, and that some part of the light to which the spectrum was due came from the umbra, became evident when the telescope was moved so as to bring the sun's limb across the slit; for then the spectrum of the light from our atmosphere was less bright than the spectrum of the umbra of the spot.

In order to obtain some estimate as to how much of the apparent light from the umbra really came from it, I made use of a graduated wedge of neutral-tint glass. The spectrum of our atmosphere at the sun's limb became so dark that the lines could not be distinguished when the part of the wedge marked 10 was before the eye. To bring

* Proceedings of the Royal Society, vol. xv. p. 256.

the spectrum of the umbra to about the same degree of invisibility the wedge had to be moved until the part marked 20 came before the eye. A photometric examination of the wedge shows that the light intercepted at 10 is to that intercepted at 20 as 1 to 3. It may then be concluded that about three-fourths of the light which formed the spectrum of the umbra was really due to the umbra of the spot.

There were several bright granules on the umbra, but the spectra of these were seen distinct from that of the umbra. Each bright point as it came upon the slit gave a narrow spectrum like a bright thread extending along the dark spectrum of the umbra.

There still remained two sources of uncertainty. 1. In consequence of the mode in which the spectrum is formed, under similar conditions of the instrument, the dark lines should appear rather thicker when the light is feebler. 2. The increased thickness of the lines in the compound spectrum might be due to the light of the umbra, or to that of our atmosphere.

The uncertainty on both these points was removed by observing the feebler spectrum of the illuminated atmosphere near the sun's limb. The lines in this spectrum, though they appeared very slightly stronger, were not so in a degree that could afford an explanation of the very marked increase of strength which most of them presented in the spectrum of the umbra. It seemed, therefore, satisfactorily determined that the light from the umbra had really suffered a more powerful absorption. The term umbra is used to include the cloudy stratum and the darker nucleus into which Mr. DAWES has shown the umbra of a spot may be usually resolved. It is probable that nearly the whole of the light under examination came from the part of the umbra known as the cloudy stratum. It was not possible to distinguish the spectra of these portions of the umbra.

The spectroscope was sufficiently powerful to show all the lines which are given in KIRCHHOFF's maps.

I carefully examined the spectrum of the umbra with that of the adjoining parts of the solar surface from A to G, but I was not able to detect any line of absorption in the spectrum of the umbra which was not also present in that of the sun's normal surface, or that any ordinary solar line was wanting in that of the umbra.

The increase of thickness, however, did not appear to take place in the same proportion for all lines. The lines C and F, due to hydrogen, appeared increased but very slightly, if indeed they were any thicker than would be due to a spectrum of feebler intensity. I incline to the opinion that these lines are not sensibly altered.

There is a small group of lines a little less refrangible than b , at 1601 to 1609, of KIRCHHOFF's scale, and which in his map are marked as coincident with lines of chromium, which was especially noticeable from increased thickness. That this circumstance was not connected with any peculiarity of the spot under examination is shown by a similar observation having been made on other spots.

Fig. 3, Plate XXXIII. represents the appearance of the double line D in the spec-

trum of the umbra. The line nearly central between the two lines may be due, in part at least, also to sodium*. These lines appeared slightly broader, as if by the addition of a faint and narrowed nebulosity at both edges.

The group of lines at B are stronger, also *b* and E. Many of the lines marked in KIRCHHOFF's map as coincident with iron appeared much stronger in the spectrum of the spot.

The absence of sensible increase in F was marked in comparison with a line or lines which were very strong, situated at a little distance on the less refrangible side of F—probably those of 2066·2 and 2067·1 of KIRCHHOFF's map.

It may be well to consider some of the conditions of the solar surface by which the phenomena observed may have been produced. A cooler state of the heated vapours by which the lines of absorption are produced, would diminish the radiation from the gas itself, and so leave more completely uncompensated the absorption by the gas of the light from behind it. This cause would produce increased blackness of the lines, but would not account for more than a slight apparent increase of breadth. The greater breadth of the lines seems to point rather to a condition of the gases in which their power of absorption embraces for each line an increased range of wave-length. That the power of absorption of gases varies in this respect is shown by the increase of breadth which some of the bright lines of some gases assume under altered conditions of tension and temperature. It will be sufficient to refer to the expansion of the lines of hydrogen as the tension increases. A similar increase in the range of its power of absorption on light passing through it should take place under similar conditions of density and temperature.

The phenomena may point to an increase of density in the vapours existing within the umbra. Such a state of things would necessarily exist at a point somewhat nearer the sun's centre; but we do not know through how great a depth of gas below the photosphere we receive the light which comes from the umbra. Our views on this point will be connected with the interpretation we give to Mr. DAWES's discovery of the existence within the umbræ of spots of a still darker part almost wholly devoid of light. Does this nucleus represent a more complete unveiling of the inner part of the sun? or does it show a still cooler and less luminous part of the down-rushing solar atmosphere? The latter suggestion, which is in accordance with the explanation of sun-spots proposed by Dr. BALFOUR STEWART, would seem to connect a lower temperature with the broader lines of absorption.

Some information might be gained if we could view the spectra of the dark pores of the solar surface, an observation which is perhaps not impossible, since these pores are of varying degrees of darkness, and are probably due to conditions of the solar substance

* The spectrum of the sodium at a high temperature is much more complex than was supposed. In addition to the three double lines besides D and a nebulous band, described in my paper "On the Chemical Elements," Philosophical Transactions, 1864, p. 147, there is a line nearly central between the lines D. It is possible there may be also other lines in the interval between the strong lines D_1 and D_2 .

beneath the photosphere, similar to those which exist in the less normal phenomenon of sun-spots.

Mr. LOCKYER'S observations and my own would seem to show that probably no considerable part of the light which emanates from the umbra of a spot is due to luminous gas. It does not appear to me that this negative evidence is of great weight as to the complete absence of light in the umbra from such a source. The luminous gas would almost certainly emit light of the same refrangibility as some of the dark lines of the solar spectrum; and if there existed above the spot the vapours of the same substances in a cooler state, the light might be wholly absorbed, and the feebler emanations of the still luminous but cooler vapours might not do more than render somewhat less intense the dark gaps produced by the vapours in the stronger light of all refrangibilities which is evidently present.

What may be the source of the light which gives the continuous spectrum of the umbra we know not. It is not impossible that the dense and intensely heated gases which probably form the inner substance of the sun, may in some cases emit lines so greatly expanded as to form, when numerous spectra are superposed, a sensibly continuous spectrum. In addition to this consideration, Dr. B. STEWART has suggested that, as gases possess a power of *general* absorption of light, a heated mass of gas if sufficiently dense to be opaque, or partly so, would give a continuous spectrum as well as the spectrum of bright lines peculiar to it. It may be that, notwithstanding the high temperature, some substances may exist in the liquid state in consequence of the pressure produced by the sun's mass.

§ VI. *Observations of Comet II., 1868.*

Received July 2, 1868.

On June 13 a comet was discovered by Dr. WINNECKE, and also independently the same night by M. BECQUET, Assistant Astronomer at the Observatory of Marseilles.

I was prevented by buildings existing near my observatory from making observations of this comet before June 22. On that evening the comet was much brighter than BRORSEN'S comet, a description of the spectrum of which I recently presented to the Royal Society*, and it gave a spectrum sufficiently distinct for measurement and comparison with the spectra of terrestrial substances.

Telescopic appearance of the Comet.—A representation of the comet as it appeared on June 22 at 11 P.M. is given in fig. 1, Plate XXXIII. The comet consisted of a nearly circular coma, which became rather suddenly brighter towards the centre, where there was a nearly round spot of light. The diameter of the coma, including the exterior faint nebulosity, was about 6' 20". The tail, which was traced for more than a degree, was sharply defined on the following edge, but faded so gradually away on the opposite side that no limit could be perceived. No connexion was traced between the tail and

* Proceedings of the Royal Society, vol. xvi. p. 386.

the brighter central part of the coma. The circular form of the coma was uninterrupted on the side of the tail, which appeared as an extension of the faint nebulosity which formed the extreme margin of the coma.

The bright roundish spot of light in the centre, when examined with eyepieces magnifying from 200 to 600 diameters, presented merely a nebulous light without a defined form.

Spectrum of the Comet.—When a spectroscope furnished with two prisms of 60° was applied to the telescope, the light of the comet was resolved into three very broad bright bands, which are represented in the diagram.

In the two more refrangible of these bands the light was brightest at the less refrangible end, and gradually diminished towards the other limit of the bands. This gradation of light was not uniform in the middle and brightest band, which continued of nearly equal brilliancy for about one-third of its breadth from the less refrangible end. This band appeared to be commenced at its brightest side by a bright line.

The least refrangible of the three bands did not exhibit a similar marked gradation of brightness. This band, though of nearly uniform brilliancy throughout, was perhaps brightest about the middle of its breadth.

These characters, which are peculiar to the light emitted by the cometary matter, must be distinguished from some appearances which the bands assumed in consequence of the mode of distribution of the light in the coma of the comet. The two more refrangible bands became narrower towards their most refrangible side, as well as diminished in brightness. This appearance was obviously not due to any dissimilarity of the light in the parts of the coma, but to the circumstance that as the light of the coma became brighter towards the centre, it was emitted by a smaller area of the cometary matter. The strong light of the central spot could be traced the whole breadth of the band; but the light surrounding this spot, in proportion as it became fainter and broader, was seen for a shorter distance, so that the light from the faintest parts near the margin of the coma was visible only at the brightest side of the band. Since in the least refrangible band a similar gradation of light did not take place, this band appeared of nearly the same width throughout.

The increasing brightness of the coma up to the brilliant spot in the centre showed itself in this band as a bright axial line fading off gradually in both directions.

On this evening I took repeated measures of the positions of these bands with the micrometer attached to the spectroscope. These measures give the following numbers for the commencement and termination of the three bands on the scale adopted in the diagram.

$$\begin{array}{lll} \text{First band} & \left\{ \begin{array}{l} 1094 \\ 1196 \end{array} \right. & \text{Second band} & \left\{ \begin{array}{l} 1298 \\ 1440 \end{array} \right. & \text{Third band} & \left\{ \begin{array}{l} 1589 \\ 1700 \end{array} \right. \end{array}$$

I could not resolve the bands into lines. When the slit was made narrow the bands became smaller both in breadth and length, from the invisibility of the fainter portions. I suspected, however, the presence of two or three bright lines in the bright central part

of the middle band near its less refrangible limit. This part would consist chiefly of light from the bright central spot.

As has been stated, the middle band commences probably with a bright line; for the limit of the band is here abrupt and distinct. On the contrary the exact point of commencement and termination of the other bands could not be observed with certainty.

I could perceive no other bands, nor light of any kind beyond the three bands, in the parts of the spectrum towards the red and the violet.

When the marginal portions of the coma were brought upon the slit, the three bands of light could still be traced. When, however, the spectrum became very faint, it appeared to me to become continuous; but the light was then so very feeble that it could not be traced beyond the three bands towards the violet or the red.

On this evening I observed the spectrum of the comet in a larger spectroscope, which gives a dispersion equal to about five prisms. In this instrument the middle band was well seen. It retained its nebulous, unresolved character, and the abrupt commencement, as if by a bright line, already mentioned, was distinctly seen.

For convenience of comparison, the spectrum of BRORSEN's comet, and that of the gaseous nebulae, have been added to the diagram, fig. 2, Plate XXXIII. The spectrum of BRORSEN's comet consisted of three bright bands and a faint continuous spectrum. These bands appeared, as represented in the diagram, narrower than those of the comet now under examination. It is not possible to say to what extent this circumstance may be due to the much feebler light of this comet. Though the bands of BRORSEN's comet fall within the limits of position occupied by the broad bands of Comet II., they do not correspond to the brightest parts of these bands. In the middle band I suspected two bright lines, which appeared shorter than the band, and may be due to the nucleus. BRORSEN's comet differed from the two small comets which I had previously examined* in the much smaller relative proportion of the light which forms a continuous spectrum. In BRORSEN's comet the bright middle part of the coma seemed to emit light similar to that of the nucleus, in the other comets the coma appeared to give a continuous spectrum. The three comets resembled each other in the circumstance that the light of the central part was emitted by the cometary matter, while the surrounding nebulosity reflected solar light.

It will be seen in the diagram that the bands of BRORSEN's comet, and those of Comet II., occupy positions in the spectrum widely removed from those in which the lines of the nebulae occur. The spectra of the gaseous nebulae consist of true lines, which become narrow as the slit is made narrower.

The following day I carefully considered these observations of the comet with the hope of a possible identification of its spectrum with that of some terrestrial substance. The spectrum of the comet appeared to me to resemble some of the forms of the spectrum of carbon which I had observed and carefully measured in 1864. On comparing the

* Comet I., 1866. *Proceedings*, vol. xv. p. 5, and Comet 1867, *Monthly Notices of Royal Astronomical Society*, vol. xxvii. p. 288.

spectrum of the comet with the diagrams of these spectra of carbon, I was much interested to perceive that the positions of the bands in the spectrum, as well as their general characters and relative brightness, agreed exactly with the spectrum of carbon when the spark is taken in olefiant gas.

These observations on the spectrum of carbon were undertaken in continuation of my researches "On the Spectra of the Chemical Elements"*. I have not presented them to the Royal Society, as they are not so complete as I hope to make them.

Though the essential features of the spectrum of carbon remained unchanged in all the experiments, certain modifications were observed when the spectrum was obtained under different conditions. One of these modifications, which was referred to in my paper "On the Spectra of the Chemical Elements"†, may be mentioned here. One of the strongest of the lines of carbon is a line in the red a little less refrangible than the hydrogen line, which corresponds to FRAUNHOFER's C. Now this line is not seen when the carbon is subjected to the induction-spark in the presence of hydrogen. Two of the other modifications of the spectrum of carbon are given in fig. 2. The first spectrum represents the appearance of the spectrum of carbon when the induction-spark, with Leyden jars intercalated, was taken between the points of wires of platinum sealed in glass tubes, and placed almost in contact in olive-oil. In this spectrum are seen the principal strong lines which distinguish carbon. The shading of fine lines which accompanies the strong lines cannot be accurately represented on account of the small size of the diagram. A spectrum essentially the same is produced when the spark is taken in a current of cyanogen. It may be mentioned that when the heating-power of the spark was reduced below a certain limit, though the decomposition of the oil still took place, the carbon was not volatilized, and the spectrum was continuous.

The third spectrum in the diagram represents the modification of this typical spectrum when the induction-spark is taken in a current of olefiant gas. The highly heated vapour of carbon emits light of the same refrangibilities as in the case of the oil; but the separate strong lines, with a similar power of spark, were no longer to be distinguished. The shading, when the carbon was obtained from olefiant gas, was not composed of numerous fine lines, but appeared as an unresolved nebulous light.

Of course in all these experiments the lines of the other elements present were also seen, but they were known, and could therefore be disregarded.

In the case of the spark in olefiant gas, the three bands in the diagram constitute the whole spectrum, with the exception of a faint band in the more refrangible part of the spectrum.

It was with the spectrum of carbon, as thus obtained, that the spectrum of the comet appeared to agree. It seemed, therefore, to be of much importance that the spectrum of the spark in olefiant gas should be compared directly in the spectroscope with the spectrum of the comet. The comparison of the gas with the comet was made the same evening, June 23.

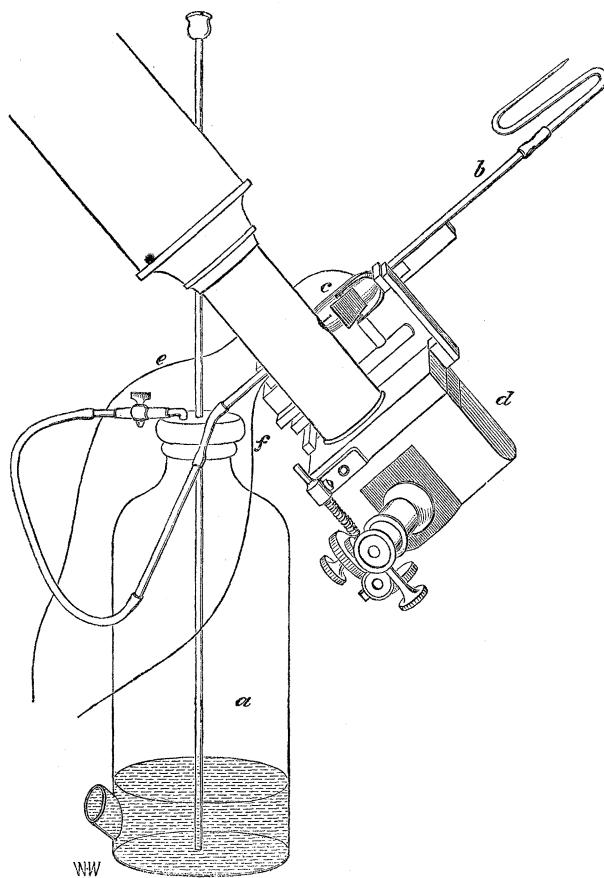
* Philosophical Transactions, 1864, p. 139.

† Ibid. p. 145.

My friend, Dr. WILLIAM ALLEN MILLER, visited the observatory on this evening, and kindly took part in the following observations.

The general arrangement of the apparatus with which the comparison was made is shown in the following diagram.

A glass bottle converted into a gas-holder, *a*, contained the olefiant gas. This was connected by means of a flexible tube, with a glass tube *b*, into which were soldered two platinum wires. The part of the tube in front of the points of the wires had been cut away, and the surfaces carefully ground. A small plate of glass closed the opening by being held in its place by a band of vulcanized india-rubber. This tube was arranged in its proper



position before the small mirror of the spectroscope *c*, by which the light of the spark was reflected into the instrument, and its spectrum was seen immediately beneath the spectrum of the comet. The spectroscope employed was furnished with two prisms of 60° .

The brightest end of the middle band of the cometic spectrum was seen to be coincident with the commencement of the corresponding band in the spectrum of the spark. As this limit of the band was well defined in both spectra, the coincidence could be satisfactorily observed up to the power of the spectroscope; and may be considered to be determined within about the distance which separates the components of the double line D. As the limits of the other bands were less distinctly seen, the same amount of certainty of

exact coincidence could not be obtained. We considered these bands to agree precisely in position with the bands corresponding to them in the spectrum of the spark.

The apparent identity of the spectrum of the comet with that of carbon rests not only on the coincidence of position in the spectrum of the bands, but also upon the very remarkable resemblance of the corresponding bands in their general characters, and in their relative brightness. This is very noticeable in the middle band, where the gradation of brightness is not uniform. This band in both spectra remained of nearly equal brightness for the same proportion of its length.

On a subsequent evening, June 25, I repeated these comparisons, when the former observations were fully confirmed in every particular. On this evening I compared the brightest band with that of carbon in the larger spectroscope, which gives a dispersion of about five prisms.

The remarkably close resemblance of the spectrum of the comet to the spectrum of carbon necessarily suggests the identity of the substances by which in both cases the light was emitted.

It may be well to state that some phosphorescent and fluorescent bodies give discontinuous spectra in which the light is restricted to certain ranges of refrangibility. There are, however, several considerations which seem to oppose the idea that the light of comets can be of a phosphorescent character. Phosphorescent bodies are usually so highly reflective that the phosphorescence emitted by them is not seen so long as they are exposed to light. This comet was still in the full glare of the sun, and yet the continuous spectrum corresponding to reflected solar light was of extreme feebleness compared with the three bright bands which we have under consideration. The phenomenon of phosphorescence seems to be restricted to bodies in the solid state, a condition which is not apparently in accordance with certain phenomena which have been observed in large comets, such as the outflow of the matter of the nucleus, and the formation of successive envelopes.

There are, indeed, some phenomena of fluorescence, such as that of a nearly transparent liquid becoming an object of some brightness by means of the property which it possesses of absorbing the nearly invisible rays of the spectrum, and dispersing them in a degraded and much more luminous form, which are less obviously inconsistent with cometary phenomena than are those of phosphorescence.

The violent commotions and internal changes which we witness in comets when near the sun seem, however, to connect the great brightness which they then assume more closely with that part of the solar force we call heat. There is also to be considered the fact of the polarized condition of the light of the tail and some parts of the comæ of comets, which shows that a part of their light is reflected.

The observations of the spectrum of Comet II. contained in this paper, which show that its light was identical with that emitted by highly heated vapour of carbon, appear to be almost decisive of the nature of cometary light. The great fixity of carbon seems indeed to raise some difficulty in the way of accepting the apparently obvious inference

of these prismatic observations. Some comets have approached the sun sufficiently near to acquire a temperature high enough to convert even carbon into vapour*. Indeed for these comets a body of great fixity seems to be necessary. In the case of comets which have been submitted to a less fierce glare of solar heat, it may be suggested that this supposed difficulty is one of degree only; for we do not know of any conditions under which even a gas, permanent at the temperature of the earth, could maintain sufficient heat to emit light, a state of things which appears to exist permanently in the case of the gaseous nebulae.

If the substance of the comet be taken to be pure carbon, it would appear probable that the nucleus had been condensed from the gaseous state in which it existed at some former period. It would therefore probably consist of carbon in a state of excessively minute division. In such a form it would be able to take in nearly the whole of the sun's energy, and thus acquire more speedily a temperature high enough for its conversion into vapour. In the liquid or gaseous state, or in a continuous solid state, this substance appears, from Dr. TYNDALL's researches, to be diathermanous. Still, under the most favourable of known conditions, the solar heat, to which the majority of comets are subjected, would seem to be inadequate to the production of luminous vapour of carbon.

It should be stated that olefiant gas when burnt in air may give a similar spectrum of shaded bands. If the gas be ignited at the orifice of the tube from which it issues, the flame is brilliantly white, and gives a continuous spectrum. When a jet of air is directed through the flame it becomes less luminous, and of a greenish-blue colour. The spectrum is now no longer continuous, but exhibits the bands distinctive of carbon. Under these circumstances, for obvious reasons, the bright lines of the hydrogen spectrum are not seen. In this way a spectrum resembling that of the comet may be obtained, with the difference that the fourth more refrangible band, which was not seen in the cometic spectrum, is stronger relatively to the other bands, than is the case when the spark is taken in olefiant gas. If we were to conceive the comet to consist of a compound of carbon and hydrogen, we should diminish in some degree the necessity for the excessively high temperature which pure carbon appears to require for its conversion into luminous vapour; but other difficulties would arise in connexion with the decomposition we must then suppose to take place; for we have no evidence, I believe, that olefiant gas or any other known compound of carbon can furnish this peculiar spectrum of shaded bands without undergoing decomposition. If, indeed, it were allowable to suppose a state of combustion, with oxygen or some other element, set up by the solar heat, we should have an explanation of a possible source of a degree of heat sufficient to render the cometary matter luminous, and which the sun's heat would be directly inadequate to produce.

* The comet of 1843 "approached the luminous surface of the sun within about a seventh part of the sun's radius. The heat to which the comet was subjected (a glare as that of 47,000 suns, such as we experience the warmth of) surpassed that in the focus of PARKER's great lens in the proportion of $24\frac{1}{2}$ to 1 without, or $3\frac{1}{2}$ to 1 with the concentrating lens. Yet that lens so used melted cornelian, agate, and rock-crystal."—Sir JOHN HERSCHEL, *Outlines of Astronomy*, 7th edit. p. 401.

There is one observation made by BUNSEN which appears to stand as an exception to the rule that only bodies in the gaseous state give, when luminous, discontinuous spectra. BUNSEN discovered that solid erbia, when heated to incandescence, gives a spectrum containing bright bands. It is therefore conceivable, though all the evidence we possess from experience is opposed to the supposition, that carbon might exist in some form in which it would possess a similar power of giving a discontinuous spectrum without volatilization. There is the further objection to this hypothesis, that the telescopic phenomena observed in comets appear to show that vaporization does usually take place.

However this may be, a state of gas appears to accord with the very small power of reflexion which the matter of the coma of this comet possessed, as was shown by the great faintness of the continuous spectrum.

A remarkable circumstance connected with comets is the great transparency of the bright cometary matter. The most remarkable instance is that of Miss MITCHELL's comet in 1847, which passed centrally over a star of the fifth magnitude. "The star's light appeared in no way enfeebled, yet such a star would be completely obliterated by a moderate fog extending a few yards from the surface of the earth"*. We do not know what amount of transparency is possessed by the vapour of carbon, but the absence of a continuous spectrum seems to show that, as it existed in the comet, it was almost perfectly transparent. The light of a star would suffer, therefore, only that kind and degree of absorption which corresponds with its power of radiation, as shown by its spectrum of bright lines. As these occur in the brightest part of the spectrum, we should expect a noticeable diminution of the star's light, if it were not for the luminous condition of the gas, in consequence of which it would give back to the beam light of precisely the same refrangibilities as it had taken, and so enable the part of the field occupied by the image of the star to appear of its original brightness, or nearly so. This state of things would not prevent an apparent diminution of the star's light from the effect upon the eye of the brightness of the surrounding field. In the case of the tails of comets, the great transparency observed is more probably to be referred to the widely scattered condition of the minute particles of the cometary matter.

I may be permitted to repeat here a paragraph from my paper on the Spectrum of Comet I., 1866†.

"Terrestrial phenomena would suggest that the parts of a comet which are bright by reflecting the sun's light, are probably in the condition of fog or cloud.

"We know, from observation, that the comæ and tails of comets are formed from the matter contained in the nucleus‡.

* Outlines of Astronomy, p. 373.

† Proceedings of the Royal Society, vol. xv. p. 5.

‡ The head of HALLEY's comet in 1835 in a telescope of great power "exhibited the appearance of jets as it were of flame, or rather of luminous smoke, like a gas fan-light. These varied from day to day, as if wavering backwards and forwards, as if they were thrown out of particular parts of the internal nucleus or kernel which shifted round, or to or fro by their recoil like a squib not held fast. The bright smoke of these jets, however, never seemed to be able to get far out towards the sun, but always to be driven back and forced into the tail as if by the action of a violent wind setting against them (*always from* the sun), so as to make it clear that the

“The usual order of the phenomena which attend the formation of a tail appears to be that, as the comet approaches the sun, material is thrown off, at intervals, from the nucleus in the direction towards the sun. This material is not at once driven into the tail, but usually forms in front of the nucleus a dense luminous cloud, into which for a time the bright matter of the nucleus continues to stream. In this way a succession of envelopes may be formed, the material of which afterwards is dissipated in a direction opposite to the sun, and forms the tail. Between these envelopes dark spaces are usually seen.

“If the matter of the nucleus is capable of forming by condensation a cloud-like mass, there must be an intermediate state in which the matter ceases to be self-luminous, but yet retains its gaseous state, and reflects but little light. Such a non-luminous and transparent condition of the cometary matter may possibly be represented by some at least of the dark spaces which, in some comets, separate the cloud-like envelopes from the nucleus and from each other.”

Now considerable differences of colour have been remarked in the different parts of some comets. The spectrum of this comet would show that its colour was bluish green. Sir W. HERSCHEL described the head of the Comet of 1811 to be of a greenish or bluish-green colour, while the central point appeared to be of a pale ruddy tint. The representations of HALLEY’s comet at its appearance in 1835, by the elder STRUVE, are coloured bluish green, and the nucleus on October 9 is coloured reddish yellow. He describes the nucleus on that day, thus:—“Der Kern zeigte sich wie eine kleine, etwas ins gelbliche spielende, glühende Kohle von länglicher Form”*. Dr. WINNECKE describes similar colours in the bright comet of 1862. “Die Farbe des Strahls erscheint mir gelbröthlich; die des umgebenden Nebels (vielleicht aus Contrast) mattbläulich.” “Die Farbe der Ausströmung erscheint mir gelblich; die Coma hat bläuliches Licht”†.

Now carbon, if incandescent in the solid state, or reflecting, when in a condition of minute division the light of the sun, would afford a light which, in comparison with that emitted by the luminous vapour of carbon, would appear as yellowish or approaching to red.

The views of comets presented in this paper do not, however, afford any clue to the great mystery which surrounds the enormous rapidity with which the tail is often projected to immense distances. There are not any known properties peculiar to carbon, even when in a condition of extremely minute division, which would help to a solution of the enigma of the violent repulsive power from the sun which appears to be exerted upon cometary matter shortly after its expulsion from the nucleus, and upon matter

tail is neither more or less than the accumulation of this sort of luminous vapour darted off, in the *first instance towards the sun*, as it were something raised up, and, as it were, exploded by the sun’s heat out of the kernel, and then immediately and forcibly turned back and *repelled from the sun*.”—Sir JOHN HERSCHEL. Familiar Lectures on Scientific Subjects. p. 115.

* Beobachtungen des Halley’schen Cometen, s. 41.

† Mémoires de l’Académie Impériale des Sciences de St. Pétersbourg, tome vii. No. 7.

in this condition only. It may be that this apparent repulsion takes place at the time of the condensation of the gaseous matter of the coma, into the excessively minute solid particles of which the tail probably consists. There is a phenomenon occasionally seen which must not be passed without notice, namely, the formation of faint narrow rays of light, or secondary tails, which start off usually from the brightest side of the principal tail, not far from the head. Sir JOHN HERSCHEL* considers that "they clearly indicate an analysis of the cometic matter by the sun's repulsive action, the matter of the secondary tails being darted off with incomparably greater velocity (indicating an incomparably greater intensity of repulsive energy) than that which went to form the primary one." The important differences which exist between the spectrum of BRORSEN's comet and that of Comet II., 1868, appear to show that comets may vary in their constitution. If the phenomenon of the secondary tails were observed in a comet which, like Comet II., 1868, appears to consist of carbon, the analytical action supposed by Sir JOHN HERSCHEL might be to separate between particles of carbon in different conditions, or possibly in a state of more or less subdivision. The enormous extent of space, sometimes a hundred millions of miles in length, over which a comparatively minute portion of cometary matter is in this way diffused, would suggest that we have in this phenomenon a remarkable instance of the extreme division of matter. Perhaps it would be too bold a speculation to suggest that, under the circumstances which attend the condensation of the gaseous matter into discrete solid particles, the division may be pushed to its utmost limit, or nearly so. If we could conceive the separate atoms to be removed beyond the sphere of their mutual attraction of cohesion, it might be that they would be affected by the sun's energy in a way altogether different from that of which we have been hitherto the witnesses upon the earth.

Though comets may differ in their constitution, reference may be permitted to the periodical meteors which have been shown to move in orbits identical with those of some comets. If these consist of carbon, we might have some explanation of the appearances presented by these meteors, though their light is doubtless greatly modified by that of the air rendered luminous by their passage, as well as by the degree of temperature to which they are raised. Carbon is abundantly present in some meteorites, but we have no certain evidence at present that the periodical meteors belong to this class of celestial bodies.

NOTE TO PLATE XXXIII.

In fig. 2, the bright line at the beginning of the middle band of the spectrum of olefiant gas is made too strong.

* Familiar Lectures on Scientific Subjects, p. 129.

Fig. 1.

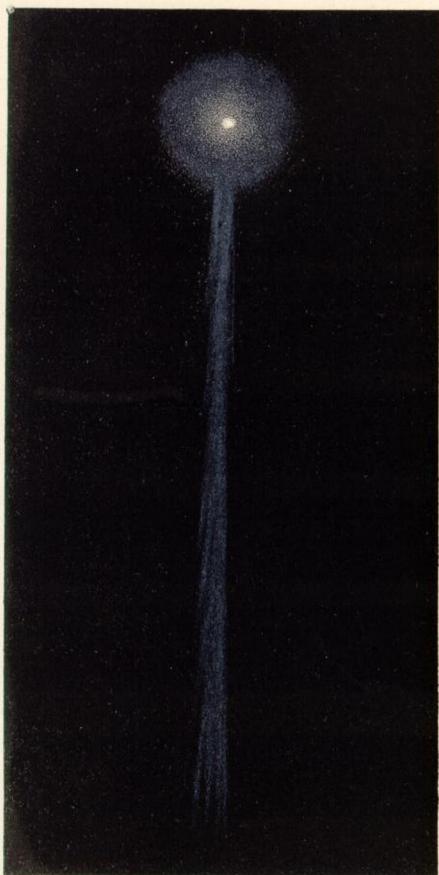


Fig. 2.

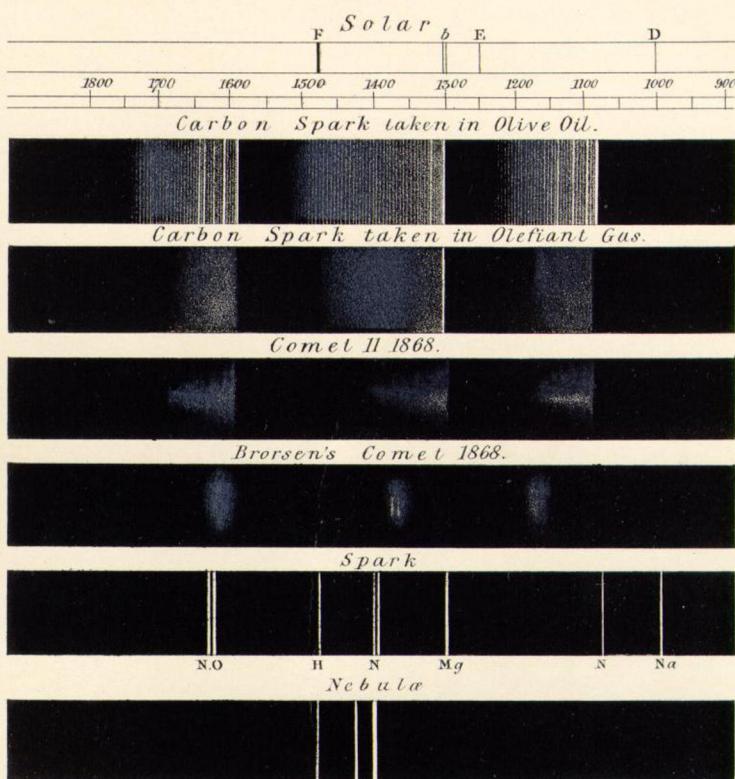


Fig. 3.

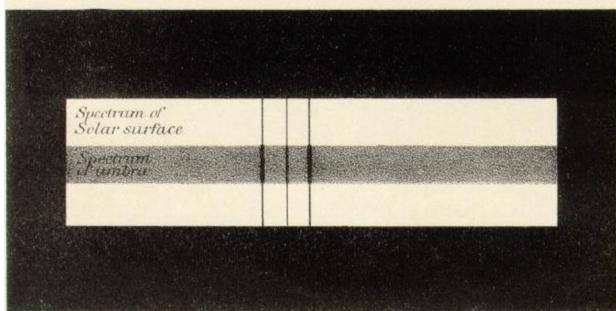


Fig. 4.

